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# EFFECT OF PLY ORIENTATION ON A CARBON FIBER COMPOSITE ANGULAR BEAM MANUFACTURING

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***ABSTRACT***

***The load-bearing capability of the carbon fiber structure with different ply orientation is studied in this paper. The material properties like Density, Volume fraction and tensile strength are experimentally known according to ASTM standards, and the remaining properties are collected from the material group; the same was used in the load analysis using ANSYS. A standard angular section is prepared using carbon epoxy material by Hand layup process to understand the challenges in the manufacturing of a composite structure. The parameters affecting the strength of the composite structure like ply orientation and manufacturing process is studied in detail. Carbon fiber reinforced composites are now being increasingly used in the automobile, aerospace and other industries due to its better out-of-plane stiffness, strength, and toughness properties. The required input data like Young's modulus, Poisson ratio, Shear modulus of the composite for structural analysis in Ansys has been practically known, and the effect of ply orientation on the performance (load carrying capabilities) of the composite structure and the challenges involved in making of composite structures is studied. The effect of ply orientation on the carbon fiber composite angular beam is studied by carrying at load analysis of beams with different ply orientations of +45$^0$, 0$^0$,90$^0$, and 0$^0$ and 90$^0$ with bi-directional ply in between using ANSYS software.***

***KEYWORDS:** ANSYS Software, Tensile Strength & Carbon Fiber*

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Original Article

## 1. INTRODUCTION

In modern years, advances in the manufacturing of composite materials and structures made them affordable for various engineering applications [1-2]. In addition to offering light-weight, composite materials are achieving both high strength and stiffness, which made them competitive to common metallic materials [3-5]. The composite material can be defined as a combination of two or more materials differing in form or composition on the macro scale, but acting in concert in combination form, retaining their identities across an interface between one another [6]. One constitute is called the reinforcing phase and the one in which it is embedded is called the matrixes: Glass fibers, Carbon fiber, Kevlar etc. composite is also defined as two or more materials are combined on a microscopic scale to form a useful third material[7-8]. Carbon fiber reinforced composites are now being increasingly used in the automobile, aerospace and other industries due to its better out-of-plane stiffness, strength, and toughness properties, lower fabrication costs and easier handling in production quality than tape laminates [9-11]. However, a material characterization of these carbon fiber laminates is essential for structural design [12]. However, a huge possibility of replacing partially the traditional synthetic fibers with natural fibres, some testing techniques are required to investigate the composite performance under periodic stress such as damping behaviour. DMA, dynamic mechanical

analysis is a useful technique in characterising the composite structure and studying viscoelastic composites [13-16]. The present research study aims to investigate the effect of carbon fiber ply orientation on sequence on the critical bulking load of beam carbon/epoxy composite laminates experimentally and using nonlinear FEM analysis using ANSYS software.

## 2. MATERIALS AND EXPERIMENTAL WORK

Characterization is essentially the process whereby materials, components, sub-systems and systems are defined in terms of their distinctive attributes, qualities, properties and functions. Composite materials behave in a complicated fashion due to macroscopic anisotropic effects and other coupling effects. Hence, the experimental characterization of composite materials is more complicated than for conventional, homogenous, isotropic materials. Since there are more independent material properties for composite materials, it is necessary to obtain more different types of data. It is also necessary to expend much effort on a selection of suitable of the test, specimens, test specimen design, fabrication and appropriate analysis of experimental data. Material characterization is done in terms of measurable parameters that the designer may relate to his design parameters

## 3. METHODS USED FOR THE PREPARATION OF COMPOSITES

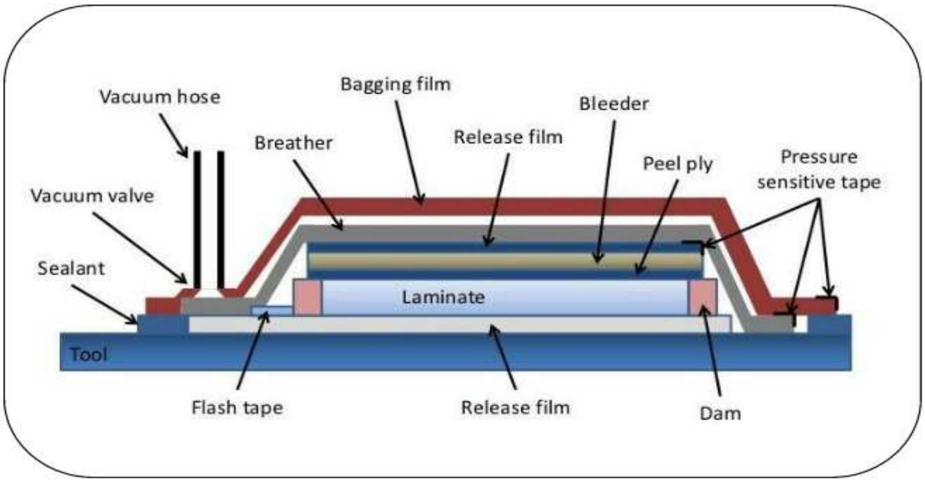


**Figure 1: Vacuum Bagging.**

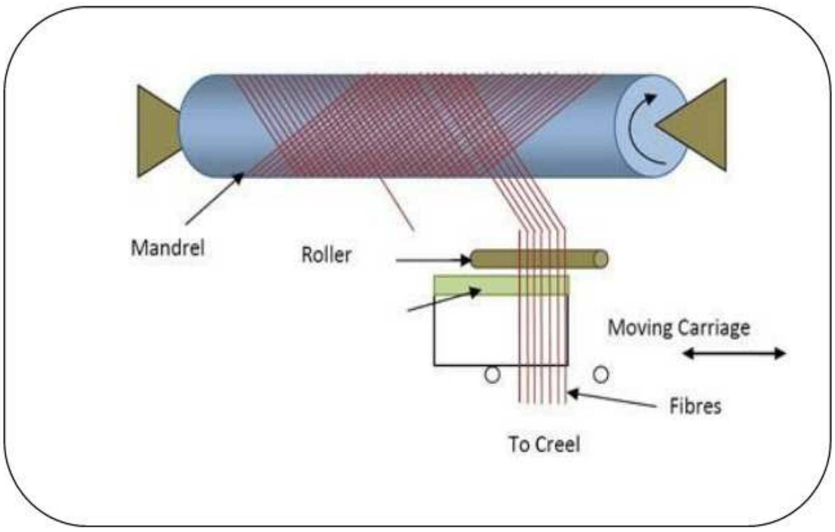


**Figure 2: Filament Winding**

This is mostly an addition of the wet lay-up process describe on top of where pressure is applied to the composite samples once laid-up to get better its consolidation. This is achieved by sealing a plastic film above the wet laid-up laminate, and onto the tool material. A vacuum pump extracts the air in the bag and accordingly, one atmosphere of pressure can be applied to the composite laminate to consolidate it

### 3.1 Filament Winding

This method is used in the fabrication of composite structures made with bendable fibers. Fibre to wear passed through a resin bath before being wound onto a mandrel in a variety of orientations, controlled by the fibre feeding mechanism, and rate of rotation of the mandrel. The wound component is then cured in an oven or autoclave. One can use epoxy resin along with any fibre. The fibre can be directly from the creel, non-woven or stitched into a fabric form. The following procedure is adopted in this paper

- Characterizing materials to be used
- Studying the composite beam at different ply orientation
  - Ansys model
  - Boundary conditions
  - Applied load
  - Hand layup Method

## 4. CHARACTERIZING MATERIALS TO BE USED

Physical properties of laminate such as resin content and fibre volume fraction are determined by acid digestion method as per ASTM D3171. For minimum characterization of a unidirectional composite, four independent elastic constants, namely the elastic moduli in longitudinal and transverse directions, the in-plane shear modulus, the major Poisson ratio and five independent strengths namely tensile and compressive strength in the longitudinal and transverse directions and the in-plane shear strength are to be determined

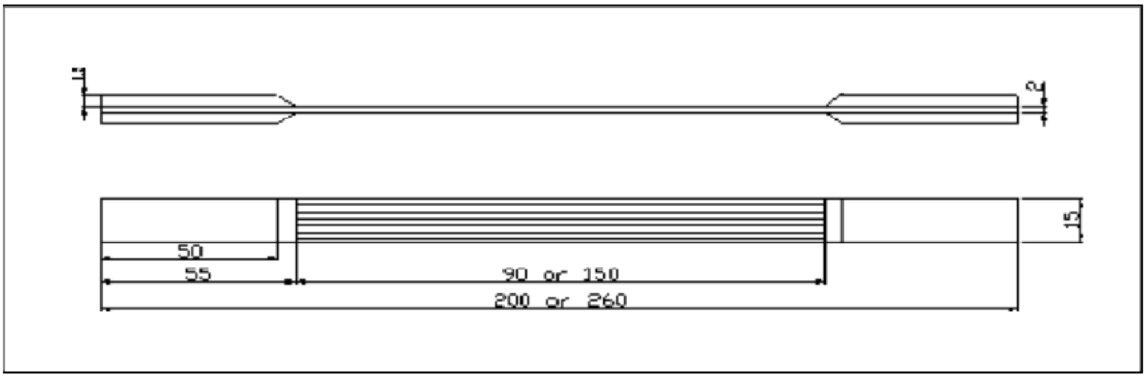


**Figure 3: Longitudinal Flat Test Specimen(ASTMD3039)**

**Table 1: Properties Required For Design And Analysis**

| Four Elastic Constants and Five Strength Parameters Data are Required for Design and Analysis of Composite Products | | |
|---|---|---|
| **Sl. No** | **Property** | **UNITS** |
| 1 | **Longitudinal** Tensile Strength | 2000Mpa(**σT11**), |
| 2 | **Longitudinal** Tensile Modulus(**E11**)- | 117GPa |
| 3 | Major Poison's ratio**ν12** | 0.29 |
| 4 | **T**ransverse Tensile Strength (**σT22**) | 14MPa |
| 5 | **T**ransverse Tensile Modulus (**E22**) | 6GPa |
| 6 | In plane shear strength (**τ12**) | 50MPa |
| 7 | In plane shear modulus (**G12**) | 3GPa |
| 8 | **Longitudinal** Compressive strength (**σC11**) | 800MPa |
| 9 | **T**ransverse Compressive strength (**σC22**) | 60MPa |

**Sample Preparation**: The samples are cut from the prepared laminates as per the ASTM Standard

**Physical Properties**: Physical properties include the determination of density, fibre volume fraction

**Density:** The procedure for measuring the density of composite material is the same as that used for any other solid and is based on ASTM specification D792**.**

## 5. FIBRE VOLUME FRACTION

The Residue is Filtered, Washed, Dried, and Weighed, and the Fibre Volume Ratio is Determined By,

$Vf = (Wf/pf)/(Wc/pc)$

Where Wf→ Weight of fibre, Wc→ Weight of composite pc→ Density of composite

pf→ Density of fibre

### 5.1 Studying the Composite Beam at Different Ply Orientation

**Composite Constituents & Identification**

Composite laminates are manufactured from the T700 grade carbon fiber and epoxy resin grade Epofine 1555 with hardener grade FH 5200

**Input Properties For Ansys: For Unidirectional Ply**

Young's modulus:- $E_x$ = 117 Gpa, $E_y$ = 6 Gpa $E_z$ = 6 Gpa,

Poisson's ratio:- νxz =0.29, $\nu_{xy}$ =0.29, $\nu_{yz}$ =0.29

Shear modulus:- Gyz = 2 Gpa, $G_{xy}$ = 3 Gpa, $G_{zx}$ = 3Gpa

**For Bi-Directional Ply**

Young's modulus:- $E_x$ = 65 Gpa, $E_y$ = 65 Gpa, $E_z$ = 6.5 Gpa, Poisson's ratio:- $\nu_{xy}$ =0.29, $\nu_{yz}$ =0.29, $\nu_{xz}$ =0.29

Shear modulus:- $G_{xy}$ = 4.5 Gpa, $G_{yz}$ = 2 Gpa, $G_{zx}$ = 4.5 Gpa

The beam created in Ansys file is of 250mm length and 50 mm width in both directions. Each ply has a thickness of 0.5mm, and the beam has a total of 10 layers of unidirectional ply; hence the thickness of the beam is 5 mm. All ten layers have same properties since they are cut from the same ply. A load of 1000 Newton's is applied on edge symmetrically

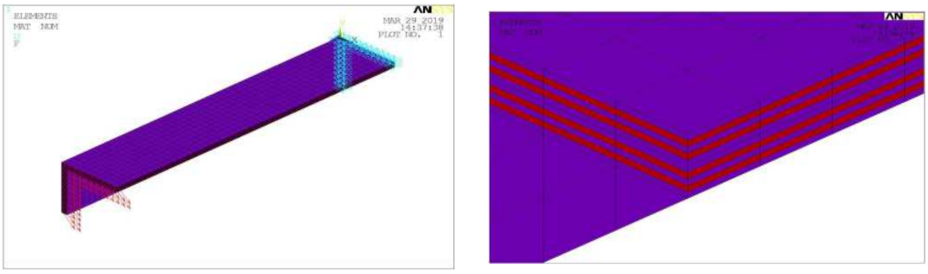

**Figure 4: Fibre Orientation:- 0 Degree (Longitudinal)**

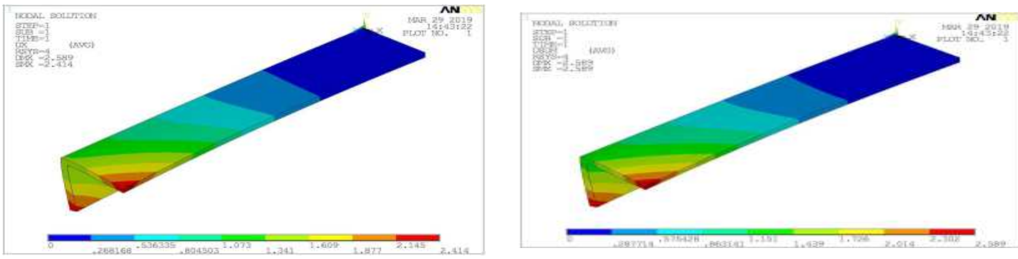

**Figure 5 The Nodal Solution in X-Direction: Nodal Solution in All Directions for longitudinal fiber oriented beam.**

**Fibre Orientation: $90^0$ Transverse**

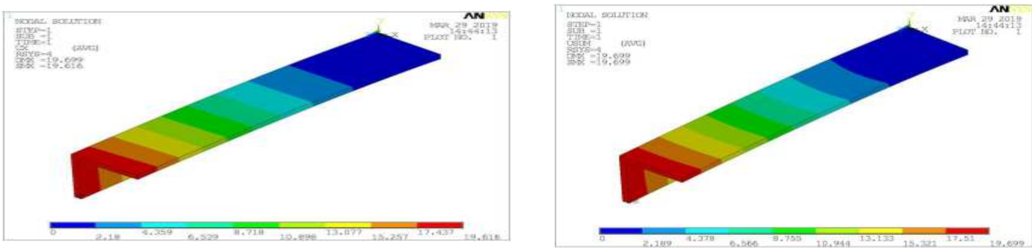

**Figure 6: The Nodal Solution in the X-Direction: Figure The Nodal Solution in all Directions For transverse fiber oriented beam.**

**Fibre Orientation: ± 45 Degree**

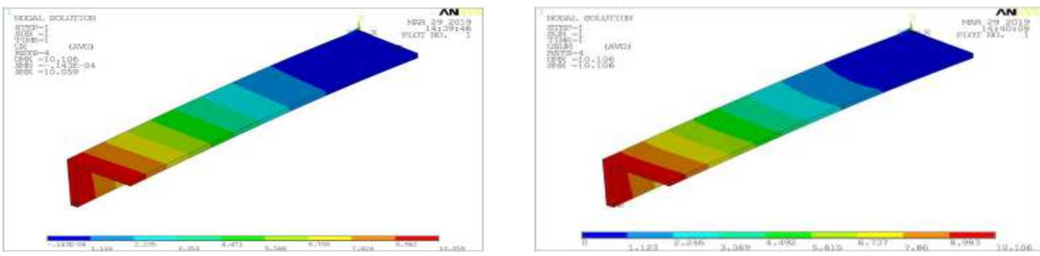

**Figure 7: Nodal Solution In The X-Direction. The Nodal Solution In All Directions for 45-degree fiber Oriented Beam.**

**Fibre Orientation: - 0 and 90 Degree with BD ply in between**

This composite beam is also of length 250mm and with 50mm width on both sides, but for this beam, there are 12 layers each of thickness 0.5 mm the orientation sequence of the beam is 0-90-0-90-0-bd-bd-0-90-0-90-0. A load of 1000 Newton is applied on edge symmetrically.

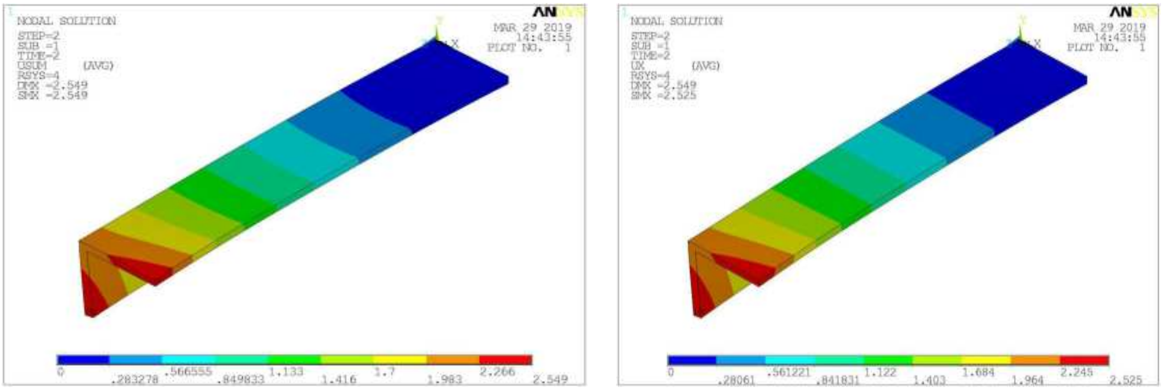

**Figure 8: The Nodal Solution in All Directions for Beam**

### 5.2 Experimentation

The following steps are involved in the preparation of beam

- Preparation of unidirectional ply.
- They are cutting the ply.
- Layup process
- Curing
- Cutting into the required dimension

**Step 1-Preparation of Unidirectional Ply**:- Materials Used

- Carbon fiber (T700Grade)
- Epoxy resin (Epofine1555)
- Hardener (Fine finishFH5200).

The ply is prepared on FILAMENT WINDING MACHINE on a cylindrical mandrel then cutting is done to the circular lamina to get a linear mat.

**Basic Principle for Preparing Ply**

The thickness of each layer is 0.5 mm, and the width depends on several spools of carbon fibre.

Rotation of Drum/Mandrel(C) = 360 X L/ W

Mixture For binding

- Resin -2kg (White gel), Hardener - 540 grams (brown gel)
- Weight ratio -100:27, When resin is heated to 500c it turns into semi liquid state.
- Then hardener is added to the resin.

**Step 2: Cutting of Ply:** The lamina with resin and hardener packed in a cover is then cut into required size and shape.

**Below Listed Specifications for 45 Degree and Mixed Section**

- Length of each lamina =300mm
- Width of each lamina =120mm
- Number of pieces to be cut with orientation 0 degrees = 4
- Number of pieces to be cut with orientation 90 degrees =4
- Number of pieces to be cut with orientation 45 degrees =10
- Number of pieces of bi-directional lamina required =2

With the above specifications, the lamina prepared from Step 1 is cutting with the help of cutter and scale is used to mark the markings required before cutting.

**Step 3: Layup Process**

**Layup for +45 Degree Right Angular Section Beam**

- A mild steel rod with a similar cross-section of the required carbon fiber beam size is taken and cleaned with acetone.
- Wax is applied on the mild steel rod.
- While laying up every layer, we must roll on them to take out the excess resin and hardener mixture.
- Rolling also helps in even distribution of fibres.
- After laying up all the layers, the layup is closed from the top with the second mild steel plate.
- Both are tied together with the help of a wire.

**Layup for Mixed Right Angular Section Beam**

- A mild steel rod with a similar cross-section of the required carbon fiber beam size is taken and cleaned with acetone.
- Wax is applied on the mild steel rod.
- The layup sequence for preparing the laminate is shown above
- While laying up every layer, we must roll on them to take out the excess resin and hardener mixture.
- Rolling also helps in even distribution of fibres.
- After laying up all the layers, the layup is closed from the top with the second mild steel plate.
- Both are tied together with the help of a wire.

**STEP 4: CURING**

After Filament winding, the laminate is cured in an oven having accurate temperature control. The flat mandrel is placed inside the oven on metal stands. The following cure cycle was followed:

- Raise the temperature of the oven from room temperature to 120ºc in 30 minutes with a heating rate of 2 to 4ºc per minute
- Hold the temperature at 120ºc ±5ºc for 3hours
- Raise the temperature of the stove from 120ºc to 160ºc in a short time with warming pace of 2 to 4ºc every moment
- Hold the temperature at 160ºc ±5ºc for 3hours
- Switch off the oven and allow the component to cool naturally
- Open the door and remove mandrel when it is below40ºc
- The length and width of every layer of the lamina as 300mm and 120mm(60mm on each side).
- But the required length and width are 250 mm and 100 mm (50mm on each side) respectively.
- Hence we check the dimension required and cut the excess portion with the help of cutters.
- The cutting can be done manually or with the help of machines.

It is concluded that the following parameters will affect the strength of the composite

- Ply orientation
- Volume fraction

Below table shows the maximum deflection of angular beam structure with different ply orientation

**Table 2: Maximum Deflection Parameters**

| Fibre Orientation | Max Deflection In X direction (mm) | Max Deflection In all directions (mm) |
|---|---|---|
| 0degree | 2.414 | 2.589 |
| 90degree | 19.616 | 19.699 |
| 45degree | 10.059 | 10.016 |
| Mixed | 2.525 | 2.549 |

## 6. CONCLUSIONS

The effect of ply orientation on the carbon fibre composite angular beam is studied by carrying at load analysis of beams with different ply orientations of $+45^0$, $0^0$,$90^0$, and $0^0$ and $90^0$ with bi-directional ply in between using ANSYS software. It is observed that the angular section with $0^0$ ply direction, i.e. along the fibre direction is deflecting less than any other orientations like $\pm45^0$,$0^0$, and $90^0$ when tested in Ansys software. The beams with $0^0$, $\pm45^0$, and $90^0$ have been manufactured, and defects that occur during the manufacture of a composite structure are identified. Realizing that $0^0$ direction beam had defects like deformed shape, holes, and uneven distribution of fibre which lead to a defective structure due to its ply orientation along the fibre direction. To solve this problem, a beam with mixed ply orientation of $0^0$ and $90^0$ with bi-direction fabric in between was also analyzed showing the similar deflection as 00 ply, the beam with mixed orientation showed fewer defects when compared to the $0^0$ fibre oriented angular beam. In this project, the required input data like Young's modulus, Poisson ratio, Shear modulus of the composite for structural analysis in Ansys is practically known, and the effect of ply orientation on the

performance (load carrying capabilities) of the composite structure and the challenges involved in making of composite structures is studied

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